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W. Alan Doolittle; Christian Wetzel; M. Asif Khan

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14. ABSTRACT

IWN 2010 was the prime forum for research results in Group-III Nitrides. The six-day event featured plenary sessions, parallel topical sessions, poster sessions and industrial exhibits. The primary goal of this Workshop was to bring the most recent development in the field to a broader audience. Broader impact could be achieved with a larger attendance by graduate students, post-doc researchers, and young faculty. ONR support was critical to the success of the Workshop as it enabled graduate students and post-docs an excellent opportunity to attend their first national meeting and to network with plenary researchers in their fields.

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Organization of International Workshop on Nitride Semiconductors in 2010

Final Report

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C. Wetzel [1] and A. Khan[2]

[1]Future Chips Constellation, Rensselaer Polytechnic Institute, 110 Eighth Street, Troy, NY 12180
[2]Univ. of South Carolina, Rensselaer Polytechnic Institute, 110 Eighth Street, Troy, NY 12180

The organizers of International Workshop on Nitride Semiconductors (IWN 2010) Marriott Waterfront Hotel, Tampa FL, Sept 19-24, 2010, appreciate the generous funding

The following is a summary of the workshop as prepared by W. Alan Doolittle, Georgia Institute of Technology and published in Compound Semiconductors Nov-Dec 2010.

LEDs and lasers are the big success stories of the III-nitride field. Thanks to the tremendous growth in device revenue, sales of nitride chips are now only eclipsed by those made from silicon. In the research community these light emitting devices are also hot, having taken up a prominent position on the conference circuit, including dominance of the two big biannual nitride gatherings: the International Workshop on Nitride semiconductors (IWN) and International Conference on Nitride Semiconductors (ICNS).

So it is not surprising that advances in the performance of blue, green, white and UV light emitters played a leading role in many of the presentations at the recent IWN 2010 meeting. However, this gathering had a noticeably different feel – one that reflected its growing maturity, which has been buoyed by the increasing diversity of III-N devices and their applications. This shift in outlook revealed itself in the vibrancy of newly added workshop sessions on power switching transistors, RF systems, and photovoltaics and energy harvesting. And it was also there in a more subtle form at the handful of social events. There nitride researchers mingled with attendees from mainstream silicon companies such as International Rectifier, National Semiconductor, and Applied Materials.

The meeting kicked off with a plenary talk by Jim Speck from the University of California, Santa Barbara (UCSB) on the growth, characterization and performance of various light emitters. Key results from his discussions included continuous-wave results on *m*-plane laser diodes operating at 459 nm with 4.1 KA/cm₂ threshold current density and a 9.8 V threshold voltage. He also detailed the challenges for growing on various non-polar and semipolar planes and justified UCBS's present focus on semipolar (2021), pointing to the higher indium incorporation on this plane and the results it has produced: 516 nm lasing and 528 nm LEDs. The collection of invited talks on the first two days also included a presentation given by one of Speck's colleagues from UCSB, the computational scientist Chris Van de Walle. He offered a new insight into an old topic, the source of yellow luminescence from carbon impurities. In addition, he described recent efforts to computationally quantify the strength of direct Auger recombination and a newly suggested process - phonon-assisted Auger. Both of these processes have a potentially important role to play in LED droop.

Delegates were also treated to an insightful presentation by Eva Monroy from CEA Grenoble, France of MBE grown inter sub-band (ISB) detectors, which included impressive TEM images. Detector results included operation well into the near IR region at 1.5 ⌈m, the first observation of ISB absorption covering the entire mid-IR range from 1.5 to 10 ⌈m and a demonstration of ISB absorption in the far IR at 9 meV. The audience was clearly impressed by efforts that not only married state-ofthe-art growth, TEM and quantum mechanical sophistication, but also provided a glimpse into the possible future of III-Nitrides.

An update of activities at the start-up Nitek was provided by Vinod Adivarahan. He revealed that the University of South Carolina spin-off, Nitek, has produced pixilated single chip LEDs operating at 280 nm with 53 mW output and hybrid/multi-chip versions with a 233 mW output at room temperature. These power levels are suitable for sterilization, UV curing and biological detection applications.

Nitride transistors

Tomas Palacios from MIT provided further evidence for the increased diversity of the III-Nitride field. In an invited talk he argued that GaN is an ideal transistor for mm- and sub-mm wave applications, before backing up his claim with a description of transistors with an f_T of 225 GHz and an f_{max} of 300 GHz, and an outline of pathways to terahertz frequencies. Palacios then set the stage for parallel sessions later that week, which focused on the rapidly emerging "low hanging fruit" that is the GaN-on-silicon power electronics market. This should be a significant percentage of the well established $ 20-40 billion silicon power device market.

Another scientist accepting the invitation to speak at the conference was Masaaki Kuzuhara from University of Fukui, Japan, who also spoke about nitride transistors. He detailed the high-temperature operation of AlGaN channeled transistors with aluminum concentrations in excess of 50 percent. These outperformed variants with a GaN channel at high temperature, opening up yet another transistor market for III-Nitrides.

Enrique Calleja Pardo from UP Madrid, Spain delivered a brilliant overview of the now well-understood mechanisms for nano-rod nucleation and growth. Pardo said that this field is "fully matured", and backed up this claim by showcasing the research of H. Sekiguchi and his coworkers (see *Appl. Phys. Lett.* 96 231104 (2010)), which details the fabrication and characterization of a full color range of nano-rod-based LEDs and many other equally impressive devices. After the opening two days of invited sessions delegates were presented with a mind-numbing smörgåsbord of choices stretching out over two days of parallel sessions. Words cannot do justice to the number of choices available.

The statistics gives a flavor, however - 385 talks and 240 posters in two days that spanned epitaxial growth; bulk crystal growth; optical, electronic and magnetic properties; device processing and fabrication technologies; defect characterization and structural analysis; theory and simulation; nanostructures; light emitting devices; electron transport devices; sensors and MEMS; plus a newly added session in photovoltaics and energy harvesting. This new session included a score of talks on photovoltaics and solar-induced water splitting.

Attendance was healthy, and some invited sessions were standing room only. They were not there to hear good news, however, but to wrestle with one of the weaknesses of nitride devices. The unavoidable truth is that today all InGaN photovoltaic results are abysmal single digit efficiencies. This poor showing stems from phase separation issues within InGaN that limit the practically achievable device energy bandgap to portions of the solar spectrum with minimal radiation. The upshot is low efficiencies.

One possible route to overcoming these issues was revealed in an invited talk by Christiana Honsberg from the Arizona State University. She presented some intriguing new results, attained in collaboration with student Michael Moseley from Georgia Institute of Technology, which outlined growth methods that can completely eliminate phase separation. Similar growth techniques have been used by Chris Boney's team from the University of Houston, and have yielded respectable currents but at lower than expected voltages. Water-splitting talks highlighted challenges with surface stability against photo-electrochemical etching. The results realized to date are highly dependent on surface treatments and measurement methodology. Several speakers also pointed out that a successful photoelectrochemical process would need to include a method for separating hydrogen and oxygen. This topic was largely outside the focus of the session.

MBE: down but not out

During the IWN meeting there was an intriguing subtle undercurrent that spontaneously emerged throughout the meeting: a resurgence in promising MBE results, particularly regarding the growth of InGaN based devices. Evidence of this resurgence could be found in the talk given by Moseley from Georgia Institute of Technology, which detailed the control of phase separation throughout the entire miscibility gap using Metal Modulated Epitaxy (MME). It was also present in Chris Boney's InGaN solar cell award winner poster, the ultra-high growth rate results from the Los Alamos National Laboratory group using their scalable ENABLE process, and also in Christina Honsberg's descriptions of the impact MME would have on InGaN photovoltaics. What's more, MBE featured in the promising nitrogen polar green LEDs reported by the Ohio State University group in the late news session and the encouragingly high hole concentration presented by student Jonathan Lowder and co-workers at Georgia Tech. Last, but by no means least, in the closing invited talk LED pioneer Hiroshi Amano pointed out that MBE and its related variants are capable of accomplishing things that other technologies struggle to achieve. While it is too early to

determine if any of these new reports will manifest into manufacturable products, IWN 2010 did highlight the promise of alternative growth technologies in a field where MOCVD dominates.

On the last day of the conference, just like the first, conference chairs Christian Wetzel and Asif Kahn gave tribute to honorary chair, Isamu Akasaki from Meijo University, Japan, for his pioneering work and leadership in the Nitride community. Fittingly, it was announced that the next IWN meeting will be held on October 14-19, 2012, at Sapporo, Japan. Hiroshi Amano from Nagoya University is taking the role of executive committee chair, with Yoichi Kawakami from Kyoto University serving as program committee chair. If the III-nitride field continues to grow at the current rate, the famous beer gardens of Sapporo that are close to the meeting will be drained dry by hoards of thirsty "Nitridors".

Rump sessions in Tampa

To maintain the workshop nature of IWN, the conference organizing committee added five rump sessions to the IWN meeting. These sessions, which gave the audience a chance to pose questions to a panel of invited experts, were highly successful with attendance bursting out of many rooms. Discussions were lively, and in some cases, playfully controversial.

The rump sessions covered:

- III-N on silicon: the best of two amazing semiconductors, which focused on how the integration with silicon enables new opportunities (and challenges) for III-N semiconductors in power electronics, optoelectronics and energy
- III-N challenges for RF electronics: which revolved around scaling, speed and reliability issues for pushing the 'standard' HEMT performance
- Ideal III-nitride substrate technology: a discussion on getting the right balance between cost of the substrate and its quality, which can enhance device performance
- LED IQE roadmap: from 70 percent to 90 percent, which looked at all the issues relating to increased efficiency
- III-N nanowires: a debate on the fundamental issues regarding growth, doping, and novel applications.

IWNS facts and figures

The International Workshop on Nitride Semiconductors 2010 was held in Tampa, Florida, from 19 to 24 September. Attendance at the meeting exceeded the previous IWN (2008) in Montreux by almost 15 percent, with 793 delegates making their way there from all over the world. 305 delegates were from North America, 255 from Asia and 204 from Europe. Following in the footsteps on previous IWN meetings, the conference started with two days of invited plenary talks, followed by two days of parallel sessions, before concluding with a mix of two plenary talks, late news, and reviews of the workshops. The traditional workshop themes, such as those of epitaxy, RF transistors and nanostructures sessions, were added to this time around, thanks to the introduction of sessions on power switching transistors, RF systems, and photovoltaics and energy harvesting.

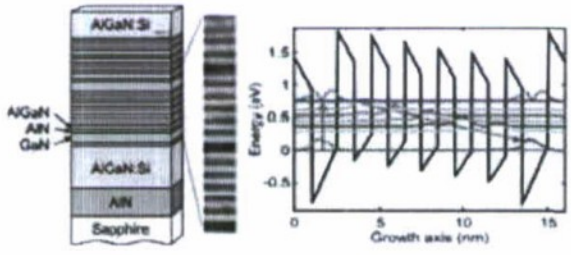

Figure 1.
Example of an inter-subband detector and quantum well design presented by Eva Monroy from CEA Grenoble, France. Structures covering the near, mid and far IR regions were demonstrated.

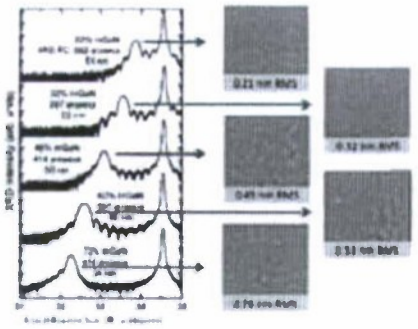

Figure 2. X-ray diffraction spectra and AFM images for MME grown InGaN throughout the miscibility gap showing single phase materials with excellent surface morphology, MBE derived techniques presented by Michael Moseley from Georgia Institute of Technology.